RoboCup@Work

Rulebook

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Contents

Chapter 1

Summary of Changes

This chapter provides an overview for experienced teams that know the rules and just need an update on what is new for the specific year. All new teams are strongly advised to read the whole rule book thoroughly.

1.1 General Rules

- The subsections ”Scoring and Ranking” and ”Restarts” have been moved to a new chapter (see 5.1).
- The following lines have been removed from section 3.3.11:
  The color of the shelf surface is a bright uniform color such as white or light gray, unless a test specifies a different color. Since the shelf is a new element in RoboCup@Work, the robots are supposed to manipulate objects only on the lower level plane.
  For more information on shelf manipulation changes see 1.2.2.

1.2 Tests

- A new sub section named ”Scoring and Ranking” has been added at 5.1. The scores for many test objectives have changed including points for successful navigation as specified in 3.4.1 in tests other than the BNT. See Table 5.2
- The new chapter ”Scoring and Ranking” now defines collisions more precisely. See section 5.5.
- The test instances have changed. For an overview see Table 5.1.
- The descriptions and rules have been rewritten for clarity and are worth revisiting!

1.2.1 Basic Manipulation Test

- The BMT now has to be started from outside of the arena and has to be finished inside the final destination.

1.2.2 Basic Transportation Test

- The different instances of the BTT have different focuses now.
- The BTT1 is a just a simple implementation of a Basic Transpotation Test. It is supposed to test the task planning capabilities for a very simple setup.
- The BTT2 is focused on different area heights. It includes all service areas of height 0, 5, 10 and 15 cm.
- The BTT3 is focused on more difficult manipulation and perception. It now contains 2 sets of containers that can be arbitrarily distributed among the 10 cm service areas and don't have to appear in pairs anymore. The test also contains shelf manipulation. For this year there will be different scoring for placing objects on the higher and lower levels of the shelf unit. This might change in following years. Note that the orientation of the manipulation objects is now be determined by the referees or the TC!

1.2.3 Precision Placement Test

- The PPT now has to be started from outside of the arena and has to be finished inside the final.
- There has been added a section to the instances table 5.1 for determining the Position, Rotation and Orientation of the PPT tiles. For this year the orientation of the tiles may be determined by the teams. This might change in following years.

1.2.4 Rotating Table Test

- The Conveyor Belt Test is now called Rotating Table Test.
- The conveyor belt has been completely removed from this test.
- The speed of the table will be determined by the OC or TC right before the test.
- The robot has to start from outside the arena and has to end in the final in order to be achieved a perfect run.
- There will be decoy objects and the position of all objects will be determined by the referees or the TC.

1.2.5 Technical Challenges

- There have been added three technical challenges to the competition that can be participated in separately from the main tests. Please see chapter 6
- The Arbitrary Surface Test (AST) will test advanced perception capabilities. THE CHALLENGES OF THIS TEST WILL BE ADOPTED IN ALL REGULAR TEST STARTING FROM 2019!
- The Line Following Test (LFT) will test advanced endeffector control following an unknown trajectory on the surface of a service area marked by a line.
- The open challenge gives teams the possibility to present whatever other scientifically relevant features and approaches they worked on.

Chapter 2

Introduction

2.1 RoboCup@Work in a Nutshell

RoboCup@Work is a new competition in RoboCup that targets the use of robots in work-related scenarios. RoboCup@Work utilizes proven ideas and concepts from RoboCup competitions to tackle open research challenges in industrial and service robotics. With the introduction of this new event, RoboCup opens up to communities researching both classical and innovative robotics scenarios with very high relevance for the robotics industry.

Examples for the work-related scenarios targeted by RoboCup@Work include

- loading and/or unloading of containers with/of objects with the same or different size,
- pickup or delivery of parts from/to structured storages and/or unstructured heaps,
- operation of machines, including pressing buttons, opening/closing doors and drawers, and similar operations with underspecified or unknown kinematics,
- flexible planning and dynamic scheduling of production processes involving multiple agents (humans, robots, and machines),
- cooperative assembly of non-trivial objects, with other robots and/or humans,
- cooperative collection of objects over spatially widely distributed areas, and
- cooperative transportation of objects (robots with robots, robots with humans).

The RoboCup@Work scenarios target difficult, mostly unsolved problems in robotics, artificial intelligence, and advanced computer science, in particular in perception, path planning and motion planning, mobile manipulation, planning and scheduling, learning and adaptivity, and probabilistic modeling, to name just a few. Furthermore, RoboCup@Work scenarios may also address problems for which solutions require the use and integration of semantic web technology, RFID technology, or advanced computational geometry.

Solutions to the problems posed by RoboCup@Work require sophisticated and innovative approaches and methods and their effective integration. The scenarios are defined such that the problems are sufficiently general and independent of particular industrial applications, but also sufficiently close to real application problems that the solutions can be adapted to particular application problems with reasonable effort.

A RoboCup@Work competition has only recently become a feasible idea for several reasons: The arrival of new, small, and flexible robot systems for mobile manipulation allow more university-based research labs to perform research in the above-mentioned areas. Advances and a revived interest in the use of simulation technology in robotics enable research groups to perform serious research without having a full set of costly robotics and automation equipment available.

The robotics and automation industry is recently shifting its attention towards robotics scenarios involving the integration of mobility and manipulation, larger-scale integration of service robotics and industrial robotics, cohabitation of robots and humans, and cooperation of multiple robots and/or humans. Last but not least, there is a huge interest by funding agencies and professional societies in well-designed and professionally performed benchmarks for industry-relevant robotics tasks. RoboCup@Work is designed as an instrument to serve all these needs.

We would like to acknowledge the following people for contributing to the development of the RoboCup@Work league.

- Rainer Bischoff
- Daniel Kazcor
- Arne Hitzmann
- Frederik Hegger
- Herman Bruyninckx
- Sven Schneider
- Jakob Berghofer

Please use the following citation for RoboCup@Work:

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@InCollection{Kraetzschmar2014,
  Title = {RoboCup@Work: Competing for the Factory of the Future},
  Author = {Kraetzschmar, Gerhard K. and Hochgeschwender, Nico and Nowak, Walter
  and Hegger, Frederik and Schneider, Sven and Dwiputra, Rhama and Berghofer, Jakob
  and Bischoff, Rainer},
  Booktitle = {RoboCup 2014: Robot World Cup XVIII},
  Publisher = {Springer International Publishing},
  Year = {2015},
  Editor = {Bianchi, Reinaldo A. C. and Akin, H. Levent and
  Ramamoorthy, Subramanian and Sugiura, Komei},
  Pages = {171-182},
  Series = {Lecture Notes in Computer Science},
  Volume = {8992}
}
```

2.2 Organization of the League

2.2.1 League Committees

The following list of committees is implemented for RoboCup@Work.

2.2.1.1 Executive Committee

Executive Committee (EC) members are responsible for the long term goals of the league and thus have also contact to other leagues as well as to the RoboCup Federation. The EC presents the league and its achievements to the RoboCup Federation every year and gets feedback to organize the league. All EC members are also members of the Technical Committee. EC members are elected by the Board of Trustees and appointed by the President of the RoboCup Federation, they serve 3-year terms. The current EC members are:

- Walter Nowak, *Locomotec GmbH*
- Nico Hochgeschwender, *Bonn-Rhein-Sieg University*

2.2.1.2 Technical Committee

The *Technical Committee* (TC) is responsible for technical issues of the league, most notably the definition of the rules, such as compliance of the robots with rules and safety standards, the qualification of teams, the adherence to the rules as well as the resolution of any conflicts that may arise during competition. The current TC members are:

- Robin Kammel, *Leibniz University Hannover*
- Sebastian Zug, *Otto von Guericke University Magdeburg*
- Benjamin Schnieders, *University of Liverpool*
- Armin Shahsavari, *Locomotec GmbH*

2.2.1.3 Organizing Committee

The *Organizing Committee* (OC) is responsible for all aspects concerning the practical implementation of competition, most notably for providing the competition arenas, ensuring their conformity with the rules, and any objects and facilities required to perform the various tests. Further, the Committee is responsible for assigning space to teams in the team area, the organization and scheduling of meetings, the nomination and scheduling of referees, the scheduling and timely execution of tests and stages, recording and publishing competition results, and any other management duties arising before, during, and after a competition. The current OC members are:

- Philipp Busse, *Otto von Guericke University Magdeburg*

- Asadollah Norouzi, *Singapore Polytechnic*
- Daniele Evangelista, *Sapienza University of Rome*

2.2.2 League Infrastructure

In order to provide a forum for continuous discussions between teams and other stakeholders, the league builds and maintains an infrastructure consisting of a web site, mailing lists, and repositories for documentation, software, and data. The infrastructure is complemented by a minimum infrastructure to be built and maintained by teams, i.e. teams should eventually create their own web page to which the RoboCup@Work League's web pages can be linked.

2.2.2.1 Infrastructure Maintained by the League

Website The official website of RoboCup@Work is at

http://www.robocupatwork.org.

This web site is the central place for information about the league. It contains general introductory information plus links to all other infrastructure components, such as a league wiki, the mailing lists, important documents such as this rule book, announcements of upcoming events as well as past events and participating teams.

Mailing Lists The league maintains several mailing lists:

`rc-work@lists.robocup.org` This is the general RoboCup@Work mailing list. Anyone can subscribe, but a real name must be provided either as part of the email address or being specified on the mailing list subscription page. The list is moderated in order to avoid abuse by spammers. New members can subscribe to this list here: http://lists.robocup.org/listinfo.cgi/rc-work-robocup.org.

`rc-work-tc@lists.robocup.org` This is the mailing list for the TC. Posts from non-members have to be approved by the list moderator. Approvals will be given only in well-justified cases.

Repositories Several repositories are publicly available under the official RoboCup@Work Github account:

https://github.com/robocup-at-work

The repositories provide among others, 3D models for the manipulation objects, PPT cavities and arena elements, as well as the sources to this rulebook, the implementation of the referee box and various tools.

2.2.2.2 Infrastructure Maintained by Teams

Each team is requested to build and maintain a minimum infrastructure for its team. This infrastructure consist of

- team web site,
- team contact, and
- team mailing address.

The team web site should contain the following information:

- Name of the team, and team logo, if any
- Affiliation of the team
- Team leader including full contact information
- List of team members
- Description of the team's research interest and background
- Description of specific approach pursued by the team
- Description of the robot(s) used by the team
- List of relevant publications by team members

The team contact should be the official contact of the team. Usually, for university-based teams, this would be an academic person such as a professor or post-doc, who should, however, be responsive and be able to answer quickly when contacted by email.

The team mailing address should be an email alias, which should be used to subscribe the team to the general RoboCup@Work mailing list. The email alias should at least include the team contact and the team leader.

2.3 Participation in the Competition

Participation in RoboCup@Work requires successfully passing a qualification procedure. This procedure is to ensure the quality of the competition event and the safety of participants. Depending on constraints imposed by a particular site or the number of teams interested to participate, it may not be possible to admit all interested teams to the competition.

2.3.1 Steps to Participate

All teams that intend to participate at the competition have to perform the following steps:

1. Preregistration (may be optional; currently by sending email to the TC)
2. Submission of qualification material, including a team description paper and possibly additional material like videos or drawings
3. Final registration (qualified teams only)

All dates and concrete procedures will be communicated in due time in advance.

2.3.2 Qualification

The qualification process serves a dual purpose: It should allow the TC to assess the safety of the robots a team intents to bring to a competition, and it should allow to rank teams according to a set of evaluation criteria in order to select the most promising teams for a competition, if not all interested teams can be permitted. The TC will select the qualified teams according to the qualification material provided by the teams. The evaluation criteria will include:

- Team description paper
- Relevant scientific contribution/publications
- Professional quality of robot and software
- Novelty of approach
- Relevance to industry
- Performance in previous competitions
- Contribution to RoboCup@Work league, e.g. by
  - Organization of events
  - Provision and sharing of knowledge
- Team web site

2.3.3 Team Description Paper

The *Team Description Paper* (TDP) is a central element of the qualification process and has to be provided by each team as part of the qualification process. All TDPs will be included in the CD proceedings of the RoboCup Symposium. The TDP should at least contain the following information in the author/title section of the paper:

- Name of the team (title)
- Team members (authors), including the team leader
- Link to the team web site
- Contact information

The body of the TDP should contain information on the following:

- focus of research/research interest
- description of the hardware, including an image of the robot(s)
- description of the software, esp. the functional and software architectures
- innovative technology (if any)
- reusability of the system or parts thereof
- applicability and relevance to industrial tasks

The team description paper should cover in detail the technical and scientific approach, while the team web site should be designed for a broader audience. Both the web site and the TDP have to be written in English.

2.4 Organization of the Competition

2.4.1 Teams

The TC and OC will jointly determine the number of teams permitted to participate in a competition well in advance. The rules shall enable a competition with up to at least 24 teams lasting not more than four full days. The number of people to register per team is not restricted by default, but may be limited due to local arrangements. Teams that plan to bring more than four members are advised to contact the OC beforehand. During registration, each team has to designate one member as team leader. A change of the team leader must be communicated to the OC. The team leader is the only person who can officially communicate with the referees during a run, e.g. to decide to abort a run, to call a restart, etc. The team leader can ask the OC to accept additional teams members for these tasks.

During on-site registration and upon request by the OC a team has to nominate one or more referees for the competition. If a team fails to provide referees in an appropriate way, the OC chooses an arbitrary member of the team for this position.

2.4.2 Team Practice and Use of Arenas

The teams will be given an opportunity to practice with their robots either in the competition arenas or in special test arenas, if available. The frequency and lengths of practice periods will be decided by the OC on site. The OC will also decide about if and how many teams may use an arena simultaneously and can decide on a practice schedule for teams wishing to use the arenas. Arenas may be modified between practice time and competition runs. The OC provides a power supply and LAN switch connecting team laptops, refbox and robots in the competion arena in order to reduce the preparation effort for the teams.

2.4.3 Stages and Tests

The OC may decide to split the competition into several stages. The competition design may foresee that only a smaller number of teams qualifies for a consecutive stage. An exemplary competition design could foresee a first stage with all qualified teams, a second stage with only the best 10 teams from the first stage, and a finals stage with the best 5 teams of the second stage.

Each stage is composed of a sequence of tests. The OC and the TC will jointly determine the type and number of tests in a stage and schedule the tests. Each test may be executed in one or multiple runs. The term run designates a single trial of a test for each team.

2.4.4 Common Procedures

One hour before a test the OC requests the capability of each team to participate. If a team cancels its participation at this point of time, it cannot withdraw the decision during the test. The order in which the teams have to perform a run is determined by a draw by the OC. The order will be made public at least 45 minutes before slot of the particular test.

A run is preceded with a 5 minutes preparation time. This time begins once the previous team has left the start area. During a run and the preparation time team members are not allowed inside the arena, except the referees allow it (e.g. to check if everything is set-up according to specification).

The preparation time starts as soon as the previous team has left the start area. If the preparation time runs out the run time will start, this can happen when the previous team is still in the arena. When a team is ready, the robot is connected and the team leader signals that the robot is ready, the time will be stopped.

When the preparation time ends, all team members must immediately leave the start area and are no longer allowed to interact with the robot, the only interactions allowed are unplugging network or power cables.

Before the tun starts the team has to check if the arena is setup correct (e.g. all manipulation objects are placed according to task specification, obstacles are placed correct). If the team is ready the run may start as soon as the previous team has left the arena.

The referees start a run by sending the start signal from the referee box.

A run ends when

- the duration for the given test has passed,
- when the task has been finished by all robots,
- when the referees decide to stop it, or
- when the team leader of the team whose turn it is decides that the run can be finished earlier as no more progress is expected.

During a run, teams may only interact with the robot or enter the area if explicitly allowed by the referees.

If the robot at any point during the run does not show any progress for 2 minutes, the run will be aborted. This includes repeating the same behavior and not leaving the start arena as a team might not be entirely prepared, or is having connection issues.

After each run, the teams must leave the arena within one minute.

2.4.5 Referees

The referees have to ensure the correct execution of the tests. They may interrupt runs if they suspect breaches of rules, see possible danger for humans or possible damages of robots and the environment. If a suspected breach of rules may be discussed after the run and cases no danger to others the run should continue, therefore the referee should announce his suspicion as fast as possible. Beside these general tasks, the referees are responsible for

- controlling the referee box (1 referee),
- supervising the robot and counting collisions (2 referees from different positions), and
- scoring results.

A team of referees supervise all runs of one test. If the referees disagree the TC will decide. The appointment of the referees has to be announced to the teams in combination with the test schedule.

2.4.6 Meetings and Language of Communication

Both the TC and the OC may organize several special meetings during a competition, such as referee meetings, team leader meetings, etc. The meetings will be announced locally. It is the responsibility of the team to inform itself about the organization and scheduling of such meetings.

Each team is expected to send at least one representative to such meetings. If the meeting refers to specific roles, such as referee or team leader, the person designated by the team to fill this role is expected to participate.

The language for all communication in the league is English.

2.4.7 Code of Conduct and Disqualification

Teams and team members are expected to maintain a friendly and cooperative atmosphere throughout a competition and contribute to a vivid work environment and to scientific exchange before, during and after a competition.

The TC may disqualify individual team members or a whole teams during a competition for severe reasons, such as repeated breach of rules.

2.4.8 Wireless LAN

A wireless LAN will be provided by the league. The usage of this WLAN is mandatory, any other WLAN is forbidden. The WLAN will be Dual-Band. There might be more then one WLAN (e.g. one per arena).

2.4.9 Use of External/Control Devices

No external devices are allowed (e.g. remote controls) in general. Exceptions may be certain simplifications leading to reduction of points as described in Section **??**, or in particular tests. All communication of the robots with external elements must be wireless. Cable connections between the robot and external devices are not allowed during competition runs.

A team may set up an additional external computer to monitor the operation of their robot(s) during a run. This monitoring system must be designed such that no manual interaction through keyboard, mouse, or any other input device is required during a run. Team members must keep their hands off the keyboards and mice of all their computers during a run. It must be clear at all times that no manual or remote control is exerted to influence the behavior of the robots during a run. Exceptions may be specified by particular tests, e.g. for tasks where handing over objects to humans is required.

Chapter 3

General Rules

Each of the particular tests defined later in this document may define its own scenario. In this document, a scenario consists of elements such as the

- environment,
- objects that affect navigation,
- objects that are to be manipulated,
- objects with which robots interact,
- number of robots allowed per team,
- number of teams competing simultaneously in the same arena,
- task to be performed by a team, and
- the criteria for evaluating a team's performance.

In order to avoid excessive development efforts for each specific test and to allow reuse of partial functionalities the scenarios are built from a reasonably small set of components, which are later put together in different ways. This section describes these elements.

3.1 Design of Robots

The robots used for competition shall satisfy professional quality standards. The concrete definition of these standards is to be assessed by the TC, comprising aspects such as sturdy construction, general safety, and robust operation. It is not required that the robots are certified for industrial use.

3.1.1 Design and Constraints

The robots need to comply with certain size constraints. A robot, including all parts attached to it as used in the competition, must be able to move by itself into a configuration so that it fits into a box of side lengths 80 cm x 55 cm x 110 cm (length x width x height). If all the robot's parts, such as manipulator or anything able to protrude outside of the previously specified box, are fully extended, the system must still not exceed a box of side lengths 120 cm x 80 cm x 160 cm (length x width x height). The organizers may specify further constraints, such as weight limits. If a team would like to apply a robot with deviating robot dimensions, it should contact the TC. Exceptions for specific robots are possible in case of small differences.

Electric, pneumatic, and hydraulic actuation mechanisms are permitted, provided that they are constructed and produced according to professional standards and meet safety constraints. Combustion engines and any kind of explosives are strictly forbidden. Robots may not pollute or harm their environment in any way, e.g. by loss of chemicals or oil, spilling liquids, or exhausting gases. Furthermore, constraints on the noise generated by a robot in operation may apply. These will be communicated in due time.

Further, the following assumptions are made about the kind of robots used in the competition:

- At least one of the robots used by a team is mobile and moves on wheels. No specific assumptions are made about the kinematic design, but the mobile robots should be able to move on basically flat, sufficiently firm surfaces.
- The robots have at least one manipulator and are able to grasp objects, which are graspable by a parallel gripper with a jaw width of at least 5 cm and do not weigh more than 300 g.
- The manipulator of the robot should be designed and mounted on the robot such that it can grasp objects from heights between 0 cm and 40 cm above the floor.
- The robots use sensors to obtain information about their whereabouts in the environment and the task-relevant objects. The major types of sensors that may be used by the robots include:
  - Laser range finders (cf. models by Hokuyo or Sick)
  - Color CCD cameras (cf. any kind of USB camera)
  - 3D cameras (cf. any kind of camera with depth information)
- The design of the scenario should be such that the robots can solve the tasks safely and robustly using (all or a subset of) these sensors.

If there are even vague doubts about the eligibility of using particular designs, parts, or mechanisms, the team should consult the TC well in advance.

The robots have to be marked such that a clear distinction of robots used by different teams during a test is possible for spectators. The OC can define the concrete types of markers to be used. In this case the markers are not taken into account when checking the robot's size constraints. The markers shall not interfere with safe operation of the robot.

The TC may require that robots are equipped with a wireless communication device of some sort (e.g. 802.11n), in order to communicate task specifications to the robots.

Future competitions may foresee the use of RFID sensors in the scenario design.

3.1.2 Behavior and Safety

In general, all robots shall be operated with maximum safety in mind. Any robot operation must be such that a robot neither harms humans nor damages the environment. A team must choose the operating parameters of their robot, e.g. the motion velocities for a robot base or a manipulator, or the grasp forces of a gripper, such that it can guarantee the safe operation of their robots.

All robots must have a mechanical mechanism for immediately stopping the robot in cases of emergency. This mechanism must be clearly visible and easily accessible. The OC may request the proof of a robot's safety (e.g. the correct operation of an emergency stop) anytime during the competition and exclude teams that cannot satisfy safety requirements.

When participating in a competition, the team may operate the robot only in their own team area, in the arenas provided (possibly constrained by a schedule assigning periods of time for exclusive use of the arena by a team or a group of teams), and in any other areas designated by the organizers for robot operation. Any operation of robots outside of these areas, e.g. in public areas or emergency paths, require prior permission by the OC.

3.2 Referee Box

The TC shall provide a referee box that supports the evaluation of the competition. It applies the time measuring, generates the tasks according to the chosen test configuration and monitors the competition. For this purpose each robot has to transmit a keep-alive signal every second during all phases (initialization, preparation, game, finish).

The referee box

1. announces the start of the preparation time,
2. communicates the task specifications,
3. starts each competition run, and
4. closes a successful run after reaching the endzone, or
5. aborts the run in case of a time lapse (indicated by a sound signal of the refbox).

When the robot is initialized, it starts immediately to transmit its beacon signal. The referee box answers with a state information. If the previous robot has left the arena, one of the referees starts the seconded phase by pushing a button. The referee box transmits a new state message that informs the robot about the beginning of the initialization phase. Inside the referee box a timer is started which initiates the start of the execution phase after transmitting the test parameters. During the run the robot is able to activate the external devices and to receive their status information. This run phase is terminated by a second timer that alerts after the duration defined in the instance table. The TC provides a Robot Operating System (ROS) based interface of the referee box as well as a reference implementation. The Referee box implementation and its documentation is available under the following link:

https://github.com/robocup-at-work/at_work_central_factory_hub

The referee box visualizes the current state of the competition run, time measurements, the task specification and robot positions for visitors. Team information (name, affiliation, contact information) are given too in this context.

3.3 Design of the Environment

3.3.1 Size of the Arena

The size of a competition arena is a rectangular area not less than 2 m x 4 m and not more than 10 m x 12 m. An orientation is always associated with the arena. An arbitrary wall is designated as North orientation, and the wall to its right is designated as East and so on. The orientations will be assigned by the local league chair or/and the TC as soon as the arena is built up. Figure 3.1 shows one possible example of an arena configuration, while Figure 3.2 illustrates the topology.

Figure 3.1: An exemplary setup of a RoboCup@Work environment.

3.3.2 Floor

The floor is made of some firm material. Examples include floors made of concrete, screed, timber, plywood, chipboard, laminated boards, linoleum, PVC flooring, or carpet. Some examples are illustrated in Figure 3.3. Floors may neither be made of loose material of any kind (gravel, sand, or any material which may damage the functioning of the robots' wheels) nor may such material be used on top of the floor. Liquids of any kind are not allowed. The floor may have spots of unevenness of up to 1 cm in any direction (clefts, rifts, ridges, etc.).

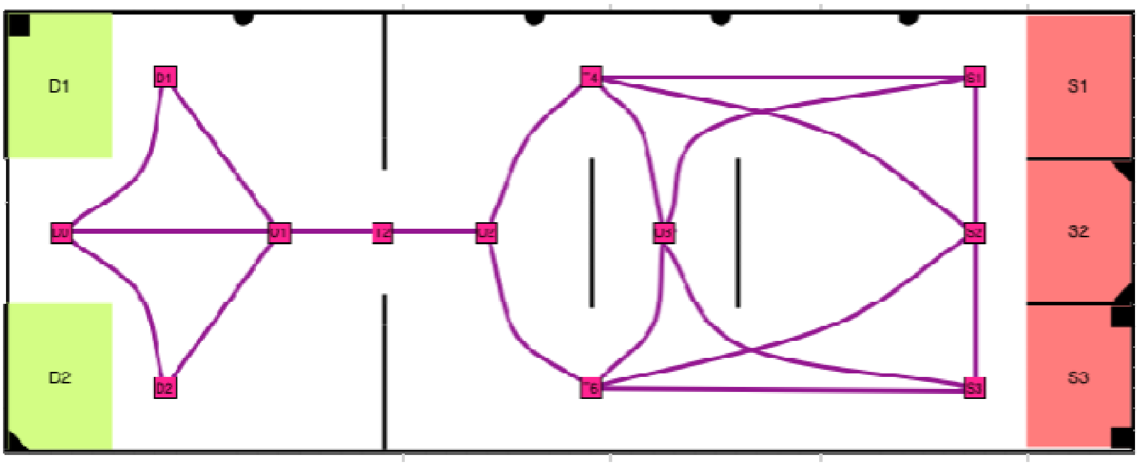
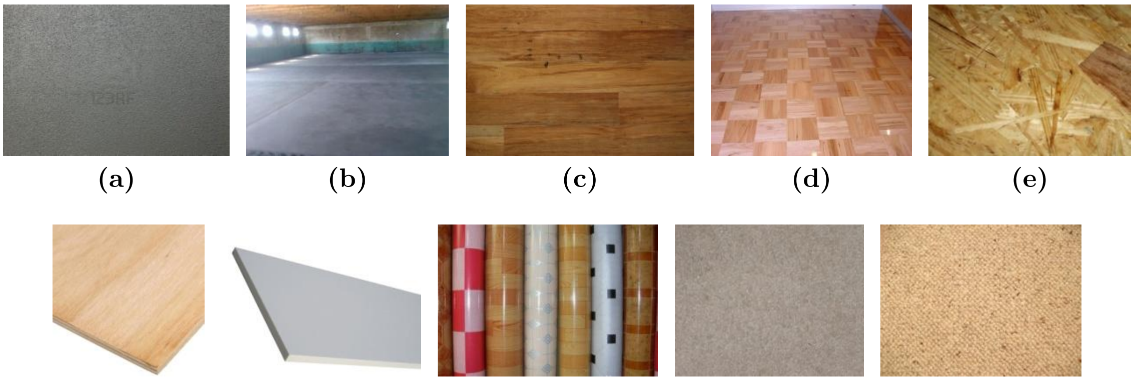


Figure 3.2: Topological map with five service areas (D1, D2, S1, S2, S3). The purple squares define places.



(a) (b) (c) (d) (e)

(f) (g) (h) (i) (j)

Figure 3.3: Examples of floors that can be used for RoboCup@Work arenas.

3.3.3 Walls

The competition arena is partially surrounded by walls. Parts of the outer border that are not blocked by walls will be marked by yellow/black barrier tape and count as virtual walls as defined in 3.3.4. The height of the walls is not less than 20 cm and not more than 40 cm. One or more gates may be foreseen, where robots can enter or leave the arena. Gates may or may not be closable. The walls have a mostly uniform color. Small visual elements like logos or advertisements may be placed on the walls.

3.3.4 Barrier Tape as Virtual Walls

The arena may include virtual walls marked by either striped yellow/black or white/red barrier tape on the floor (see Figure 3.4).

There are two types of yellow/black barrier tape to be considered.

- The outer border of the arena that is not blocked by actual walls will be marked by this tape. If any part of a robot passes over such a tape it is considered as a collision with a usual wall and will be penalized according to section 5.1.
- There may be barrier tapes on the floor of the arena that do not mark an outer border, but instead are supposed to mark a dangerous zone and are also not to be crossed. The penalty for those collisions can be found under section **??**. NOTE: These collisions will also be considered a major collision in following years.

The red/white tape is used to frame the entrance and exit area. The robot is allowed to cross this kind of barrier only at the beginning of a test to enter arena and at the end for leaving. In contrast, the yellow/black one denotes an obstacle which the robot is never allowed to cross.

The blue/white tape is not considered a virtual wall but marks the areas of 0 cm height (see Section 3.3.9).

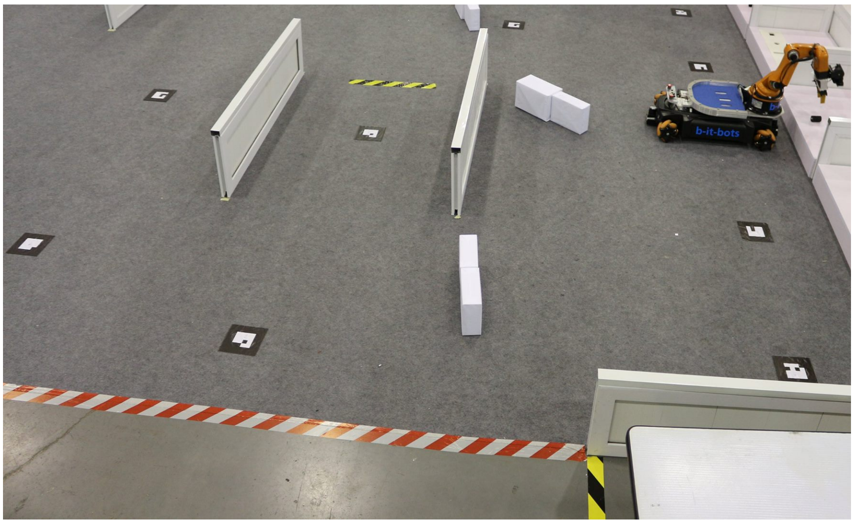


Figure 3.4: Example of barrier tape used during RoboCup 2015. The red/white tape is used for the entrance and exit, while the yellow/black one denotes an obstacle.

3.3.5 Entrance and Exit

If possible, the arena should have one entrance and one exit, which are equipped with laser barriers. These barriers are used for timekeeping by the referee box.

3.3.6 Places

An arena designed for a particular test may foresee the definition of a set of designated places, which are locations in the arena that can be referred to by a unique, symbolic identifier. These identifiers are used e.g. for the task specification, possibly in conjunction with other information, such as an orientation. Places may be marked by markers of some sort.

3.3.7 Floor Markers

The arena used for a particular test may foresee the use of floor markers for designated places. The design of these floor markers are rectangular black-and-white images as used by the AR-ToolKit library:

http://www.hitl.washington.edu/artoolkit

The black inner square of the markers is at least 8 cm x 8 cm large with an additional white border around of at least 12 cm side length. Figure 3.5 and 3.4 depict some examples of these markers.

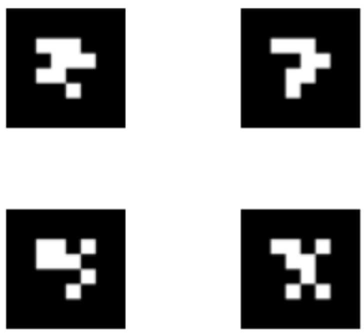


Figure 3.5: Example of a floor marker.

3.3.8 Obstacles

An arena defined for a particular test may foresee the use of obstacles. Obstacles may by passive (i.e. not able to relocate by themselves) or active (e.g. other robots). The size of obstacles should be not lesser than 10 cm x 10 cm x 5 cm; there is no upper bound on the size. The details about the dynamic objects are not known before the competition and will be chosen by the OC or TC on-site. Examples for obstacles are trash bins, boxes, big aluminium profiles or even other robots.

3.3.9 Service Areas

Arenas contain one or more service areas, which have specific purposes for a particular test. Examples include loading and unloading areas, rotators, storage areas, etc. Service areas may contain specific environment objects, such as shelves, racks, etc. They may be accessible from different locations, i.e. it might be possible to reach an area from two or more sides. Note that service areas can have different heights. If a service area has a height of zero cm, a tape will mark the area (see Figure 3.6). The tape will be on the floor and will be blue/white striped. The surounded area is covered by a white sheet of paper fixed by the tape. The OC is responsible to replace it in case of pollution or tears. This tape may be crossed, and does not count as a collision. If the robot touches an manipulation object while navigating, this will be handled as a collision.

Figure 3.6: Barrier tape used to mark service areas with 0 cm height.

3.3.10 Containers

As in many industrial settings, the RoboCup@Work environment may be equipped with several containers (see Figure 3.7). They can store any kind of manipulation object defined in Section 3.5.2. Robots are supposed either to grasp one or multiple objects out of containers or to place previously grasped objects into them. Several containers can be present in the environment and are always associated with a service area. That means that the container itself will be placed on top and within the manipulation zone defined in Section 3.5.1. It is also possible that more than one container is placed on top of a single service area. The constraints defined in Section 3.5.1 apply also to the containers.

Currently, a container itself does to not need to be manipulated or transported by the robot.

3.3.11 Shelves

Service areas may foresee the use of shelves and shelf units as depicted in Figure 3.8. Objects to be delivered or removed from shelves have to be placed or picked sideways. The height of the shelves should be not lesser than 5 cm and not be more than 40 cm. The shelf surface may be specially designed in order to serve specific purposes, e.g. holding objects.

(a) blue (b) red

Figure 3.7: Containers can be used for grasping objects out or placing objects into them.

Figure 3.8: A shelf with two levels and uniform colored surfaces.

3.4 Design of Navigation Tasks

Every task has some navigation involved in it. Successful navigation will be awarded in every test according to Table 5.2. If not defined differently in the respective test, a navigation is successful when the robot reached the service area as defined in section 3.4.1.

This rule has been implemented so that new teams can participate in every test and earn points, even if they are not capable of manipulating objects reliably.

3.4.1 Reaching a Service Area

A service area counts as successfully reached if the robot is within a reasonable range, which is usually its "arms reach". The reasonable range will be subjectively evaluated by the referees.

3.5 Design of Manipulation Tasks

3.5.1 Manipulation Zone

The manipulation zone defines the area where objects can be placed. Thereby, the following constraints need to be satisfied:

- The maximum depth of the manipulation zone is 20 cm.
- The minimum distance between objects to each other is 2 cm.
- The minimum distance of the beginning of the manipulation zone to a wall is 10 cm.
- There as an offset of 2 cm from the border of the service area to the manipulation zone.

Note, the constraints do not permit, that objects can be partially occluded dependent on the viewpoint.

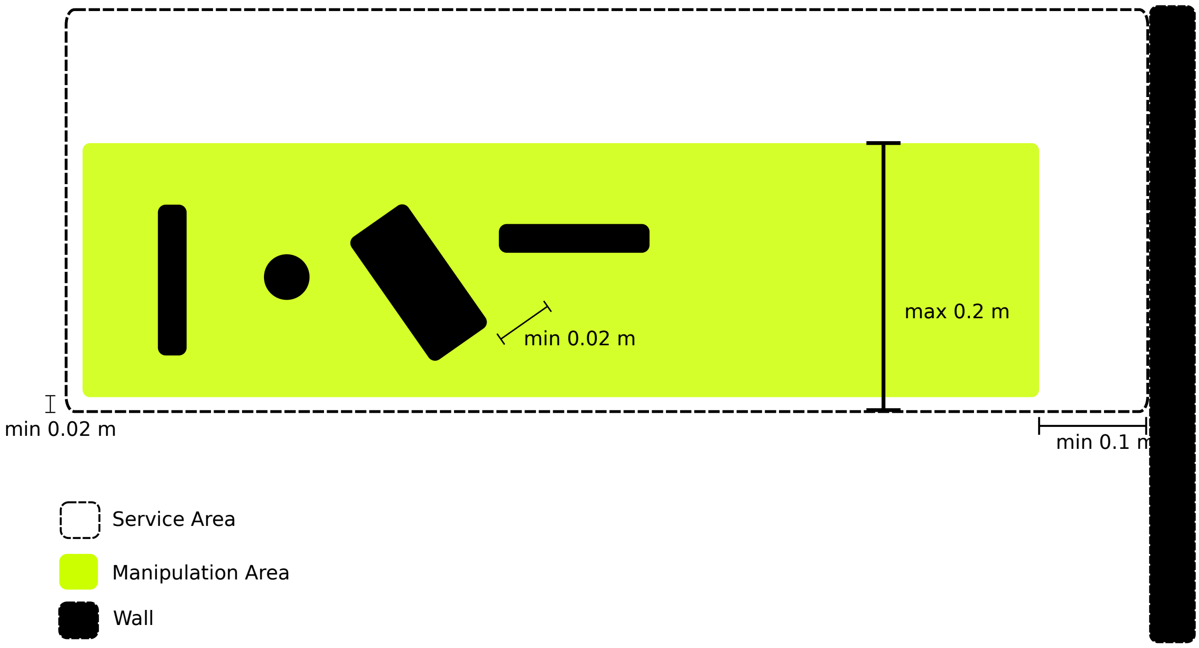


Figure 3.9: Manipulation zone: the green color indicates the area where objects can be placed on a service area by the referees.

3.5.2 Manipulation Objects

The manipulation objects in RoboCup@Work shall include a wide range of objects relevant in industrial applications of robotics. They eventually cover any raw material, (semi-)finished parts or products as well as tools and possibly operating materials required for manufacturing processes.

The intention is to start with a simple set of objects of different shapes and colors. Every year, the spectrum shall then be widen in at least one aspect. The initial set of objects includes basic standard screws and nuts with various sizes and masses as shown in Table 3.1 and Table 3.2. Objects of one kind can slightly vary e.g. considering the surface.

For the placement of manipulation objects the following terms are used:

- Position: point within 2D coordinate system of a service area,
- Rotation: rotation around vertical axis of a service area,
- Orientation: rotation around horizontal axes of a service area, i.e. whether the object is standing upright or lying on its side
- Pose: combination of position, rotation and orientation.

3.5.3 Grasping Objects

If not specified differently in a test, the following definition applies to decide if an object counts as being grasped from a service area.

An object counts as grasped from a service area, when the object was moved outside of the source service area. Outside means, that the vertical projection of the objects convex hull does not touch the service area any more.

The last point shall enable to let the robot pick up an object in order to analyse its type, e.g. by holding it close to a camera on the robot.

If the robot handles an object, but does not fulfill all points above, the object does not count as being grasped, and neither points for grasping a required object, nor penalty points for grasping an unspecified object are given. Still, if the object drops to the ground or an uncontrolled collision occurs, the normal penalty points apply.

3.5.4 Placing Objects on Service Areas

If not specified differently in a test, a manipulation object counts as placed on a target service area if any part of the object is touching the surface of the service area and the object is not moving at the end of the run. An objects does not count as placed when it is dropped (e.g. dropped from a height above 5 cm). This is to avoid that robots throw objects and potentially harm people or property.

The pose of the object on the service area can be chosen freely by the robot.

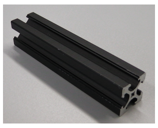
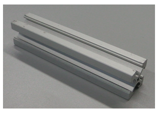
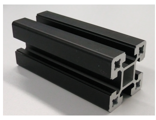
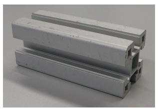
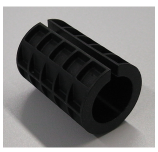
Object	Symbolic Description	Mass	Details
	F20_20_B	49 g	Small aluminium profile (black) Height: 20 mm Width: 20 mm Length: 100 mm
	F20_20_G	49 g	Small aluminium profile (gray) Height: 20 mm Width: 20 mm Length: 100 mm
	S40_40_B	186 g	Big aluminium profile (black) Height: 40 mm Width: 40 mm Length: 100 mm
	S40_40_G	186 g	Big aluminium profile (gray) Height: 40 mm Width: 40 mm Length: 100 mm
	M20_100	296 g	Screw ISO 4014 M20 Length: 100 mm
	M20	56 g	Small nut ISO 4032 M20
	M30	217 g	Big nut ISO 4032 M30
	R20	14 g	Plastic tube Inner diameter: 20 mm Outer diameter: 30 mm Length: 45 mm

Table 3.1: RoboCup@Work manipulation object set.

Object	Symbolic Description	Mass	Details
	`Bearing_Box`	102 g	Bearing box Height: 25 mm Width: 45 mm Length: 50 mm Inner diameter: 32 mm
	`Bearing`	42 g	Bearing Height: 13 mm Inner diameter: 15 mm Outer diameter: 32 mm
	`Axis`	40 g	Axis Diameter: 27 mm Length: 96 mm
	`Distance_Tube`	5 g	Distance tube Height: 10 mm Inner diameter: 28 mm Outer diameter: 32 mm
	Motor	20 g	Motor Diameter: 42 mm Length: 87 mm

Table 3.2: RoCKIn manipulation object set.

Chapter 4

Tests

The actual competition contains of a set of so-called tests. A test is specified in terms of it's purpose and focus, environment features and eventually manipulation objects involved. Further, a concrete specification of the task is given and the rules to be obeyed.

Each test has different variability dimensions. That is, which objects to be manipulated, how many locations to visit, from which height to grasp etc. The test instances for 2018 are defined based on the general test description and can be seen in Section 5.1.

4.1 Basic Navigation Test

Purpose and Focus of the Test The purpose of the *Basic Navigation Test* (BNT) is to check whether the robots can navigate well in their environment, i.e. in a goal-oriented, autonomous, robust, and safe way.

As the navigation problem is in the focus of robotics research for a long time and many approaches for solving it and its subtasks (like exploration, mapping, self-localization, path planning, motion control, and obstacle avoidance) exist, the focus of this test is to demonstrate that these approaches function properly on the robots used by the teams and in the environment defined by the test.

Scenario Environment The arena used for this test contains all elements that affect or support navigation: walls, service areas, places, arena objects, wall markers, and floor markers. In addition, obstacles may be placed in the environment.

Manipulation Objects This test does not include any objects for manipulation.

Task The robot will be sent a task specification, which is a string containing a series of triples, each of which specifies a place, an orientation, and pause duration. The robot has to move to the places specified in the task string, in the order as specified by the string, orient itself according to the orientation given, cover a place marker, pause its movement for the time in seconds as specified by the pause length, and finally leave the arena to reach the final position.

The task specification consists of:

– A destination location, e.g. `WS01`, `SH02`, `CB03` or `WP12`
– An orientation (`N`, `S`, `W`, `E`)
– A duration in seconds

The duration is always set to 3 seconds in order to make validation easier for the referees.

Rules The following rules have to be obeyed:

- A single robot is used.
- The robot has to start form outside the arena and to end in the final.
- The order in which the teams have to perform will be determined by a draw.
- After the team's robot enters the arena, it must move to the places given in the task specification and assume the orientation specified after the place. The robot may reach a destination by choosing any path.
- The robot must visit the places in the order given by the task specification. It is possible to skip a place of the task specification and continue with the next one. In cases where the

robot skipped one or multiple places there may be multiple possible matchings between places reached and places specified. In that case for calculating scores the matching is taken which leads to the highest score for the team.

- A destination is counted as reached when the robot covers the place marker for the number of seconds specified by the break and does not move (very small movement of the wheels is allowed). The orientation must not deviate more than 45 degrees.
- The run is over when the robot reached the final place or the designated time has expired.

4.2 Basic Manipulation Test

Purpose and Focus of the Test The purpose of the *Basic Manipulation Test* (BMT) is to demonstrate basic manipulation capabilities by the robots, like grasping, turning, or placing an object.

The focus is on the manipulation and on demonstrating safe and robust grasping and placing of objects of different size and shape. Therefore, the number of service areas will be constraint to two, one source area and one target area, which are close to each other.

Scenario Environment Additionally to environmental elements, different manipulatable objects will be placed on the specified service areas.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 5.1.

Task The task consists of a sequence of grasp and place operations, with a small base movement in between. The objective is to move a set of objects from one service area into another. To complete the task the source and the target destination have to be reached at least once.

The task specification consists of:

– The specification of the initial place
– A source location, given as place (any one)
– A destination location, given as place (any one, but nearby the source location)
– A list of objects to manipulated from the source to the destination service area
– The specification of a final place for the robot

Rules The following rules have to be obeyed:

- The order in which the teams have to perform will be determined by a draw.
- The robot will get the task specification from the referee box.
- A service area counts as successfully reached as defined in Section 3.4.1
- A manipulation object counts as successfully grasped as defined in Section 3.5.3
- A manipulation object counts as successfully placed, if the robot has placed the object into the correct destination service area as described in Section 3.5.4.
- The run is over when the robot reached the final place or the designated time has expired.
- The score for this test will be calculated as defined in 5.1.

4.3 Basic Transportation Test

Purpose and Focus of the Test The purpose of the *Basic Transportation Test* (BTT) is to assess the ability of the robots for combined navigation and manipulation tasks as well as its task planning capabilities. The robots have to deal with flexible task specifications, especially concerning information about object constellations in source and target locations, and task constraints such as limits on the number of objects allowed to be carried simultaneously, etc.

Scenario Environment The arena used for this test contains all elements as for the Basic Manipulation Test. Besides that all areas may contain objects.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 5.1.

Task The task is to get several objects from the source service areas (such as `SH02`, `WS09`, or `CB02`) and to deliver them to the destination service areas (e.g. `WS11` and `SH05`).

The task specification consists of two lists: The first list contains for each service area a list of manipulation object descriptions. The descriptions are similar as those used for the Basic Manipulation Test. The second list contains for each destination service area a configuration of manipulation objects the robot is supposed to achieve. The configuration specification is similar as used in the Basic Manipulation Test.

The term "line" in the task specification can be ignored.

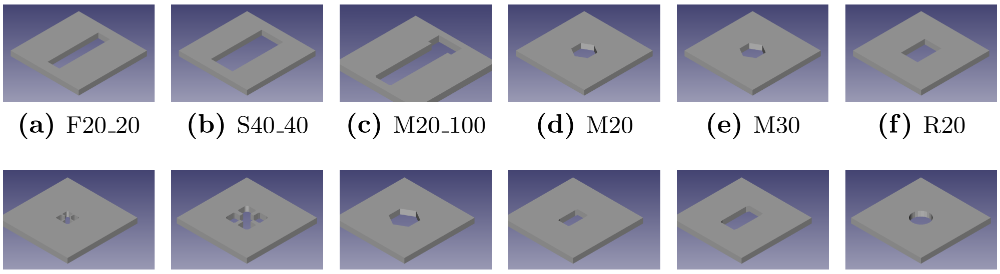
Rules The following rules have to be obeyed:

- A single robot is used.
- The robot has to start from outside the arena and to end in the final.
- The order in which the teams have to perform will be determined by a draw.
- The robot will get the task specification from the referee box.
- A service area counts as successfully reached as defined in Section 3.4.1
- A manipulation object counts as successfully grasped as specified in Section 3.5.3.
- A manipulation object counts as successfully placed as specified in Section 3.5.4.
- It is not allowed to place manipulation objects anywhere except for the robot itself and the correct service areas.
- A robot may carry up to three objects at the same time.
- The run is over when the robot reached the final place or the designated time has expired.
- The score for this test will be calculated as defined in 5.1.

4.4 Precision Placement Test

Purpose and Focus of the Test The purpose of the *Precision Placement Test* (PPT) is to assess the robot's ability to grasp and place objects into object-specific cavities. This demands advanced perception abilities (to recognize the correct cavity for each object) and manipulation abilities (to grasp and place the object in such a manner that it fits into the cavity).

Scenario Environment The same arena as for the Basic Manipulation Test is used. In case that the arena does not already include a modified service area as shown in Figure 4.2, it will be added only for this particular test. The modified service arena includes object-specific cavities as shown in the Figure 4.1. For each object used in the test, there will be one specific cavity. The cavity has the dimension of the object plus a 2 mm offset for each dimension. At most five cavities are used in the test.



(a) F20_20 **(b)** S40_40 **(c)** M20_100 **(d)** M20 **(e)** M30 **(f)** R20

(g) F20_20 **(h)** S40_40 **(i)** M20_100 **(j)** M20 **(k)** M30 **(l)** R20

Figure 4.1: Illustration of horizontal (top row) and vertical (bottom row) cavities for the different kind of manipulation objects.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 5.1.

Task The objective of the task is to pick the objects which are placed on one service area and make a precise placement in the corresponding cavity at the service area with the special PPT platform (an example configuration is illustrated in Figure 4.2).

The task consists of multiple grasp and place operations, possibly with base movement in between, which will, however, be short. Note that the placement of the object in the cavity is finished when the object is fallen into the cavity (i.e. at least some part of the object has to touch ground floor underneath the cavity).

Rules The following rules have to be obeyed:

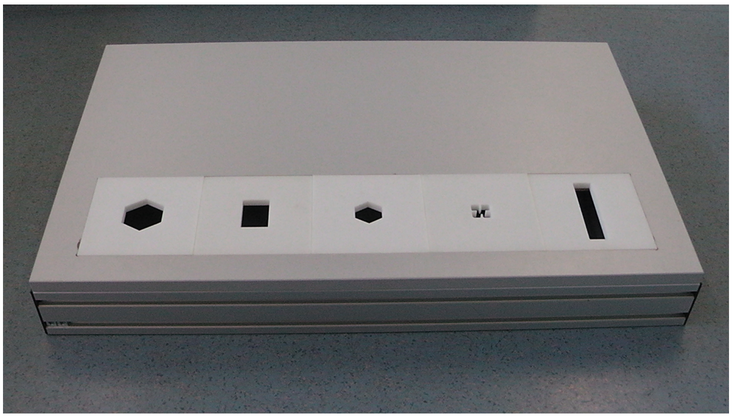


Figure 4.2: The PPT platform including five cavity tiles

- A single robot is used.
- The robot has to start from outside the arena and to end in the final.
- The order in which the teams have to perform will be determined by a draw.
- The robot will get the task specification from the referee box.
- A service area counts as successfully reached as defined in Section 3.4.1.
- An object counts as placed correctly if it fell through the correct cavity and touches the ground beneath. It may happen that an object blocks the cavity for the next object, e.g. by standing upright on the floor. In that case a referee may remove that object (which remains to count as a successful place). If the referee is not able to do so and the robot places another object into the blocked cavity, it counts as a correct placement if it would have been successful without the blocking object.
- The run is over when the robot reached the final position or the designated time has expired.
- The score for this test will be calculated as defined in 5.1.

4.5 Rotating Table Test

Purpose and Focus of the Test The purpose of the *Rotating Table Test* (RTT) is to assess the robot's ability to manipulate moving objects which are placed on a rotating turntable. The test demands fast perception and manipulation skills in order to pick up objects from a moving surface.

Scenario Environment The same arena as for the Basic Manipulation Test is used. In case that the arena does not already include such a device (see Figure 4.3), it will be added only for this particular test.

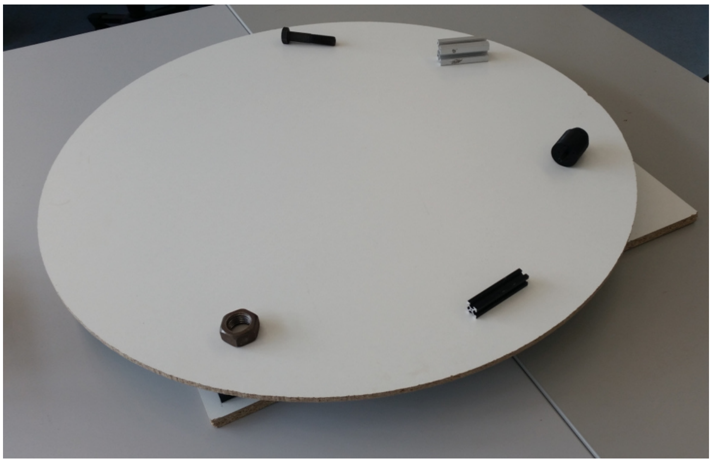


Figure 4.3: Illustration of a rotating table used in the competition.

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 5.1.

Task The task of the robot is to navigate to the location of the rotating table and to grasp all objects from the moving table. The objects can pass multiple times in front of the robot, until the maximum time for the run is over. The robot is supposed to place the grasped objects on the robot itself.

Rules The following rules have to be obeyed:

- A single robot is used.
- The robot has to start from outside the arena and to end in the final.
- The order in which the teams have to perform will be determined by a draw.
- The objects are placed on the rotating table before the run starts by the OC or TC.

- The speed of the rotating table is determined by the OC or TC just before the test starts.
- The robot will get the task specification from the referee box.
- A service area counts as successfully reached as defined in Section 3.4.1
- A manipulation object counts as successfully grasped as specified in Section 3.5.4.
- The objects have to be grasped actively from the moving table. The robot is not allowed to stop the items with its gripper.
- The run is over when the robot reached the final position or the designated time has expired.
- The score for this test will be calculated as defined in 5.1.

Chapter 5

Scoring and Ranking

5.1 Scoring

For each test the calculation of scores is defined individually, comprising points for achieving certain subtasks, points for winning a run and penalty points.

Each test provides a set of so-called feature variations encoding the overall variability of the test (e.g. whether obstacles can occur or not, number and type of manipulation objects). To enhance comparability among different test runs, all teams will have to perform the same test instances as specified in Table 5.1.

If not specified otherwise, the following set of scoring rules applies for each test:

Explanation of the terms:

- Correct navigating is defined in Section 3.4.1
- Correct grasping is defined in Section 3.5.3
- Correct placing is defined in Section 3.5.4

5.2 Simplifications

Teams may use simplifications, which will result in a reduction of scores for the given run:

- Use of external sensors: -200 points
- Use of other external objects (e.g. to support localization): -100 points
- Use of own loading or unloading areas: -200 points

Additional simplifications are specified for individual tests. These reductions do not count as penalty points. Teams that want to make use of the simplifications above have to announce them in advance of the competition to the TC. The TC might forbid the use of specific elements for simplification if these are not in the spirit of the league or may cause disproportionate advantages for a team.

5.3 Perfect Runs

All teams fully complete a perfect run will receive a completion bonus of 0.75 points per second left on the run time. These points are only awarded if the run is perfect, i.e. all objectives reached without any penalties.

5.4 Penalties

Penalty points are given as follows, each time again the incident occurs:

- A manipulation object is lost or placed anywhere outside of a service areas: -100 points
- Delivering a wrong manipulation object to service area -50 points
- Minor collision (see Section 5.5): -50 points
- Major collision (see Section 5.5): -50 points and termination of the run

5.5 Collisions

For reasons of safety of people and property it is strictly unwanted for the robot to collide with any of the environmental objects. Only collisions of the manipulator with the upside of the service area are allowed. The different kind of collisions that can occur are defined in the following subsections.

5.5.1 Minor Collision

If the robot collides with the environment, but does not move the environment and the wheels are not spinning, it is considered a minor collision.

5.5.2 Major Collision

If the robot collides with the environment and moves it or its wheels are spinning, it is considered a major collision.

5.5.3 Barrier Tape collision

If any part of the robot touches a barrier tape, it is considered a barrier tape collision. The maximum penalty resulting from these collisions depends on the specific competition instance and is listed in Tab. 5.2.

Touching or passing a Barrier Tape when entering or exiting the arena does not count as collision.

5.6 Restarts

Teams might use one so-called restart in a run. Restarts have the following aspects:

- Per run, at most one restart is allowed for a team, if not specified otherwise in a test.
- At any time during a run, the team can call for a restart to the referees.
- When the referees acknowledge the call for restart, the team may enter the arena. The time will continue running.
- The arena and the robot will be reset exactly to the setup at the beginning of the run (except the timer for the run). Random elements such as obstacles or object positions remain like before.
- The points for this run achieved so far are reset to zero.
- Scores that are received after a restart are multiplied by a factor of 0.75.
- The referees decide when the arena is prepared again for the restart. If the robot is not yet ready, teams can keep trying to get it ready until the time for the run is over.
- As soon as the team signals that the robot is ready, the task specification is sent again.
- Afterwards the start signal is sent from the referee box.

5.7 Ranking

The tests will occur in the instances shown in Table 5.1. Ranking of the teams will be based on the sum of the achieved points over all the tests.

A team cannot get less than zero points for one run. The scores of the tests of the first stage are summed up, and the teams with the highest sums proceed to the next stage.

In case of a tie, the OC will either schedule a deciding run or continue with a higher number of participants.

				Instances							
				① BNT	② BMT	③ BTT1	④ BTT2	⑤ BTT3	⑥ PPT	⑦ RTT	⑧ Final
Manipulation	Objects	RoboCup@Work & RoCKIn	RefBox		5	5	6	6	3	3	10
		Decoy	RefBox			3	3	3		3	5
		Table height	RefBox		10 cm	10 cm	0 cm 5 cm 10 cm 15 cm	10 cm	10 cm	10 cm	0 cm 5 cm 10 cm 15 cm
	Grasping	Shelf unit	RefBox					2			2
		Position			Ref	Ref	Ref	Ref	Team	Ref	Ref
		Rotation			Team	Ref	Ref	Ref	Team	Team	Ref
		Orientation			Team	Team	Team	Ref !	Team	Team	Ref!
		Rotating turntable	RefBox							3	1
	Placement	Cavity platform with decoy	RefBox						3		1
		Shelf unit	RefBox					1			1
		Red container	RefBox					2			2
		Blue container	RefBox					2			2
		Rotating turntable	RefBox				1				
Arena	Cavities	Position	RefBox						Ref		Ref
		Rotatoion	RefBox						Ref		Ref
		Orientation	RefBox						Team		Team
		Obstacles (static)	Referee	2			2	2			2
		Barrier tape	Referee	2		2		1			2
		Waypoints	RefBox	9							
Duration			RefBox	5 min	5 min	5 min	8 min	8 min	4 min	4 min	10min

Table 5.1: Test specification in the instances of the RoboCup@Work 2018 competition.

	Instances							
	① BNT	② BMT	③ BTT1	④ BTT2	⑤ BTT3	⑥ PPT	⑦ RTT	⑧ Final
Correct destination reached	50							
correct service area reached		25	25	25	25	25	25	25
Correct object grasping standard		100	100	100	100			100
round table							200	200
Correct object placing standard		75	75	75	75			75
PPT area						250		250
shelf upper level					150			150
shelf lower level					300			300
Incorrect object placing		-100	-100	-100	-100	-100		-100
Incorrect object grasping			-100	-100	-100		-100	-100
Completing whole task	50	75	100	100	250	50	75	300
Maximum barrier tape penalty	100		200		300			400
Maximum attainable points (time bonus not included)	500	1000	1050	1300	1400	850	700	2300

Table 5.2: Scoring in the instances of the RoboCup@Work 2018 competition.

Chapter 6

Technical Challenges

In order to value very specific capabilities required in RoboCup@Work technical challenges are part of RoboCup@Work. These challenges are designed to be included into the major competition after they have shown a potential as a benchmark in industrial robotics and have been at least solved in principal. Each technical challenge is separately awarded. That means, teams can participate in any number of them.

6.1 Arbitrary Surface Test

6.1.1 Purpose and Focus of the Test

The purpose of the *Arbitrary Surface Test* (AST) is to introduce different kinds of surfaces for the work stations in order to make the operating environment more realistic. In real life scenarios the robot might have to pick objects from different colored or dirty places. Also there could be other industrial items on the surface area that the robot must avoid. This challenge focuses on an advanced perception ability of the robot.

The main goal of the challenge is to show a reliable and robust vision of the robot during picking operations.

NOTE: The challenges of this test will very likely be transferred to all regular tests from 2019 on!

6.1.2 Scenario Environment

The arena used for this test contains basically all elements as for the Basic Manipulation Test. Additionally to environmental elements (walls, service areas, floor markers, etc.), an object with an arbitrary surface color (see Fig. 6.1) will be added to one of the service areas. The referees will prepare the surface on a manipulation zone with a height of 10cm. All geometrical definitions given in Fig. 3.9 are considered here too.

(a) **(b)**

Figure 6.1: Examplary configuration of the working desks

6.1.3 Task

The task consists of navigating to the specified location and then picking three objects from the service area. There will also be three to five decoy objects that must not be picked up.

The task consists of a sequence of grasp operations. The objective is to pick up all objects specified in the task spec and avoid picking other objects.

The task specification consists of:

- The specification of the initial place
- A source location, given as place (e.g. `WS09`)
- A list of objects to be picked up from the source service area
- The specification of a final place for the robot

Manipulation Objects The manipulation objects used in this test are defined by the instances described in Table 5.1.

6.1.4 Rules

The following rules have to be obeyed:

- A single robot is used.
- The robot has to start from outside the arena and to end in the final.
- The order in which the teams have to perform will be determined by a draw.
- At the beginning of a team's period, the team will get the task specification.
- A service area counts as successfully reached as defined in Section 3.4.1
- Three objects have to be picked.
- There will be 3 decoy objects that must not be picked on the service area.
- A manipulation object counts as successfully grasped as specified in Section 3.5.3.
- The run is over when the robot reached the final place or the designated time has expired.

6.1.5 Scoring

- 100 points are awarded for each correctly and succesfully picked object
- -50 points for every incorrectly picked object
- 25 points for reaching the correct service area
- 25 points for reaching the final position

6.2 Line Following Test

6.2.1 Purpose and Focus of the Test

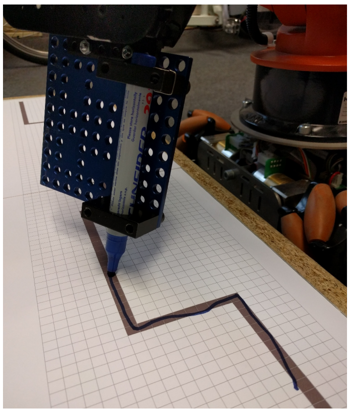
The purpose of the *Line Following Test* (LFT) is to address a common task for industrial robots - following a plain trajectory. For welding, gluing or painting processes this is implemented by non-mobile manipulators. This challenge extends the complexity and focuses on a combined motion by manipulator and platform.

The main goal of the challenge is to show a precise operation of the TCP. A successful completion includes the detection of the trajectory and the movement of a pen along the line.

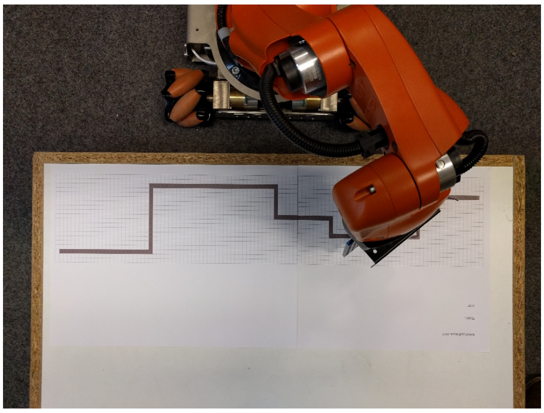
6.2.2 Scenario Environment

The arena used for this test contains basically all elements as for the Basic Navigation Test. Additionally to environmental elements (walls, service areas, floor markers, etc.), an object with a contour on a flat surface (see Fig. 6.2) will be added to one of the service areas. The line is constructed based on a 8x8 mm grid. The referees affix the printout defining the trajectory on a manipulation zone with a height of 10 cm. All geometrical definitions given in Fig. 3.9 are considered here too. The trajectory combines just horizontal or vertical line elements and does not include loops. An exemplary pdf file is available in the RoboCup@Work repository.

Each participating team is free to choose an appropriate pen type and assemble them to the TCP.



(a) Examplary TCP equiped with a pen



(b) Top view perspective on the test

Figure 6.2: Examplary configuration of the trajectory

6.2.3 Task

The task consists of navigating to the specified location and then moving the pen along the defined contour.

The task specification consists of the specification of the workstation place (e.g. `WS09`).

6.2.4 Rules

The following rules have to be obeyed:

- A single robot is used.
- The robot has to start from outside the arena and to end in the final.
- The order in which the teams have to perform will be determined by a draw.
- The given trajectory is equal for all teams.
- At the beginning of a team's period, the team will get the task specification.
- The run is over when the robot reached the final place or the designated time has expired.

6.2.5 Scoring

The referees count the number of grids within the area of the correct line and grids with pen traces outside. At least 25 coherent grid elements have to be identified for a valid run!

- 10 points are awarded for each marked grid within the given trajectory
- -5 points for every grid element outside of the gray contour

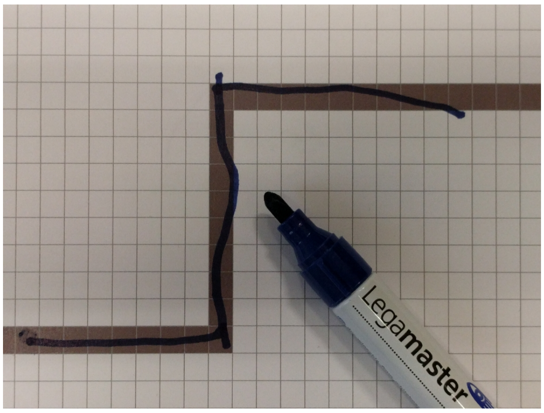


Figure 6.3: Examplary result - 28 valid grid, 4 invalid grids

6.3 Open Challenge

During the Open Challenge teams are encouraged to demonstrate recent research results and the best of the robots abilities. It focuses on the demonstration of new approaches and applications to industrial tasks.

6.3.1 Task

The Open Challenge consists of a demonstration and an interview part. The performance of the teams is evaluated by a jury consisting of all team leaders, TC and OC members. Although it is supposed to be an open demonstration and the teams shall have freedom to develop their own ideas, a scientific and industrial tie will be considered in the jury's assessment. The topic of the demonstration should focus on one or multiple fields of the RoboCup@Work league namely robot manipulation, robot navigation and mapping, object detection and recognition.

1. Setup and demonstration: The team has a maximum of 7 minutes for setup, presentation and demonstration.
2. Interview: After the demonstration, there is another 3 minutes where the team answers questions by the jury members.

6.3.2 Presentation

During the demonstration, the team can present the addressed problem and the demonstrated approach. A video projector or screen, if available, may be used to present a brief (max. 1 minute) introduction to what will be shown. The team can also visualize robots internals, e.g., percepts.

6.3.3 Jury evaluation

Jury: All teams have to provide one person (preferably the team-leader) to follow and evaluate the entire Open Challenge. A jury member is not allowed to evaluate and give points for the own team. The present members of the TC and OC will join the jury.

Evaluation: Both the demonstration of the robot(s), and the answers of the team in the interview part are evaluated.

For each of the following evaluation criteria, a maximum number of points (as defined by equation 6.1) is given per jury member:

- Overall demonstration
- Robot autonomy in the demonstration
- Realism and usefulness for industrial like applications (Can this be ported on real industrial scenarios?)

- Novelty and (scientific) contribution
- Difficulty and success of the demonstration

The maximum points for each criterion is calculated as:

$$S_{c,max} = \frac{MaximumPointsForThisChallenge}{NumberOfEvaleuationCriteria} \tag{6.1}$$

The maximum points for this challenge is 200 in RoboCup@Work 2018.

Normalization and outliers:

- The total score for each team is the mean of the jury member scores. To neglect outliers, the N best and worst scores are left out:

$$S = \frac{\Sigma TeamLeaderScore}{NumberOfTeams(2N+1)} \tag{6.2}$$

$N = 2$ if $NumberOfTeams \geq 10$, 1 if $NumberOfTeams < 10$.

Chapter 7

Open Source Award

7.1 Introduction and Motivation

In order to foster the development of new teams and to increase cooperation among established teams, the league announces an Open Source Award. As demonstrated in other RoboCup major leagues, releasing software and/or hardware as open source fosters the overall progress of the league. Similarly, to other open source awards in RoboCup, all institutions, persons and teams who took part in national and international RoboCup@Work competitions in 2018 or the previous year are eligible to participate.

7.2 Application

The application should contain the following items:

- A technical report and description (max. 8 pages in Springer LNCS style) about the open source artifact (software/hardware or both). The report should briefly describe the open source project objectives, design decisions and most importantly should exemplify it's importance for the RoboCup@Work competition and community.
- A online reference, documentation, tutorial (e.g. website, Github page etc.) for the presented open source material. This includes also statements about licensing (e.g. which kind of open source license such as GPL, LGPL, Apache, etc.) and usage.

Application deadline is the: 01.05.2016. Application material needs to be send via email to: `rc-work-tc@lists.robocup.org`. Please note, in case the evaluation committee receives only applications which do not fulfill the desired level of quality, the award will not be given in 2018. The winner(s) will be announced during the RoboCup 2018 award ceremony.

7.3 Evaluation

Evaluation is performed by an external jury chosen by the EC and TC. The evaluation criteria are the following:

- Relevance: *Is the presented material relevant for RoboCup@Work? Can the material be applied in the context of RoboCup@Work?*
- Originality: *Does the presented material solve a problem/issue in RoboCup@Work in a very appealing, general approach?*
- Technical Quality: *Is the presented material well-designed and well-developed. This also includes coding style etc.?*
- Presentation: *Is the presentation of the material appealing and complete for RoboCup@Work purpose?*